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PORTON TECHNICAL PAPER No. 860

TRAINING AND PERSONALITY AS DETERMINANTS OF
EXERCISE HYPERVENTILATION - FACTORS AFFECTING
THE TESTING OF PHYSICAL INCAPACITATION IN MAN.

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K.H. KEMP and R.J. SHEPHARD.

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PORTRON TECHNICAL PAPER NO. 860

DATE: 1st June, 1963.

TRAINING AND PERSONALITY AS DETERMINANTS OF EXERCISE
HYPERVENTILATION - FACTORS AFFECTING THE TESTING OF
PHYSICAL INCAPACITATION IN MAN

By

K.H. Kemp and R.J. Shephard

SUMMARY

1. Ventilatory and cardiac responses to the riding of an electrically braked bicycle ergometer have been investigated in young male subjects during a variety of short intensive training regimes involving both maximal and sub-maximal work. In most experiments rides were repeated thrice daily, for one or two weeks.
2. With "maximal effort" rides of 5 min duration, there was an increase in the rate of working over the training period (greater with 1 ride per day than with three rides per day), and this increase was sufficient to mask any improvement of cardiorespiratory performance.
3. With longer periods (15 or 30 min) of heavy but sub-maximal work, there was a progressive reduction of both the ventilatory and the cardiac response to exercise, and calculations suggested that the efficiency of external work was also increased. The magnitude of these changes could be related to initial "fitness".
4. Changes in respiratory quotient with repetition of the sub-maximal rides suggest that with habituation, there was less hyperventilation. Both at rest and during exercise, the cardiorespiratory performance could be related to personality type, as assessed by the Maudsley Personality Inventory.

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5. Excessive ventilatory work can itself limit performance, and for this reason personality and the psychological approach to successive work periods can influence both initial working capacity and also the response to a training regime.
6. The application of these findings to the testing of physical incapacitation is discussed.
7. An Appendix gives details of the ergometer used in these tests.

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INTRODUCTION

The establishment of a reliable procedure for the evaluation of human working capacity is a necessary corollary of our current interest in physical incapacitating agents. The present paper considers factors affecting the performance of one laboratory test of physical capacity, the riding of a bicycle ergometer. This test was selected in preference to other procedures such as the treadmill and the step test for two main reasons:-

- (1) there is less scope for variation in techniques of working,
- (2) the rate of working is more readily measured and standardized.

Changes in the ventilatory and cardiac responses to exercise with repetition of the test are described, the influence of type of training schedule, initial "fitness" and personality of the subject on the results is examined, and a procedure for the testing of physical incapacitation is suggested.

METHOD

1. Design of the experiment

Seventy three young men were studied at rest and during and after the riding of an electrically braked bicycle ergometer. The training schedules were as follows:-

- (a) 6 men - 5 min "maximal" effort once daily for 5 days.

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- (b) 10 men - 5 min "maximal" effort thrice daily for 5 days.
- (c) 31 men - 15 min constant effort (125 watts, 746 kg.m/min) thrice daily for 5 days.
- (d) 14 men - 15 min constant effort (125 watts, 746 kg.m/min) thrice daily for 10 days*
- (e) 10 men - 30 min constant effort (125 watts, 746 kg.m/min) thrice daily for 5 days.
- (f) 2 men - 30 min constant effort (105 watts, 626 kg.m/min) thrice daily for 5 days.

Measurements were made for 15 min before, during, and for 15 min after the first run of each day of respiratory minute volume, output of mechanical work, cardiac rate, and, in group (d) only, of rectal temperature, oxygen consumption, and carbon dioxide output. The later runs each day were for "training" purposes and the only observations made were of the output of mechanical work. In all subjects, an objective numerical assessment of "personality" type was made by Maudsley personality inventory⁽¹⁾.

2. Experimental procedure

Subjects The 73 subjects ranged in age from 18-40 yr. On arrival at the laboratory, details of the tests were explained in simple terms, physical characteristics were measured, and the initial state of "training" and experience of bicycle riding assessed.

"Training" was rated on a four point scale:-

	<u>Grade</u>
Subject taking no regular exercise	4
Subject regularly playing one active sport	3
Subject regularly playing one active sport with specific training session	2
Subject regularly playing more than one active sport with specific training sessions	1

All of the subjects had ridden a bicycle previously, 14 having been club or long (>60 miles) distance cyclists six months or more prior to the tests. However, at the time of testing, only 10/73 were bicycling regularly, and

* 2 periods of 5 days, with weekend break of 2 days.

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seven of these 10 were only bicycling short distances ($\frac{1}{2}$ - 5 miles/day).

The Maudsley personality inventory was completed during the morning of the second day, and subjects were allocated to 5 arbitrary "personality" groups on the basis of their "N" and "E" scores, as follows*:-

	"N" score	"E" score
"Normal" personality (n)	< 28	< 34
"Anxious" personality (a)	> 28	< 20
"Hysterical" personality (h)	> 28	21-27
"Psychopathic" personality (p)	> 28	> 28
"Extravert" personality (e)	< 28	> 35

Ergometer test conditions. Experiments were conducted in a quiet draught free room. Ambient temperatures were constant to within $\pm 1^{\circ}\text{C}$ for a series of tests on any one subject, but the mean temperatures ranged more widely from 14°C to 20°C for different subjects. Clothing was serge (battledress) trousers and flannel shirt for the "maximal" effort experiments, and shorts and running vest for the constant effort tests. The first run of each day was made in the morning, one hour after breakfast. Subjects remained seated on the bicycle (saddle height adjusted to optimum), and gripped the handlebars throughout the tests.

Ergometer. Details of the bicycle ergometer are given in the Appendix to this report. The "load" was provided by a shunt-wound car dynamo and an adjustable external electrical resistance. A pedal speed of 45 r.p.m. consumed 154 watts and corresponded to a road speed of about 10 m.p.h. on a normal 26 in. wheel bicycle. Work output was indicated by a low inertia motor counting unit, and a simple calibration curve enabled this to be converted to standard electrical units (watts). Counter readings were recorded at 1 min intervals during the period of work.

* No clinical significance is attached to these categories of personality. From the clinical standpoint, all of the individuals tested would be considered "within normal limits".

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Respiratory and cardiac measurements

Subjects used a standard box valve and mouthpiece, and expired gas was passed to a dry gasmeter (resistance < 32 mm H₂O with flow having respiratory waveform and peak of 250 l./min) for the measurement of respiratory minute volumes. Readings were taken at $\frac{1}{2}$ min intervals for 15 min before, during, and for 15 min after a ride. "Resting" ventilation was determined as the average value for the 6th - 15th min on the bicycle; the extra ventilation during work and recovery was calculated to give (i) total extra ventilation (exercise and recovery) for a given rate of external work (E.V., l./min/watt, and (ii) average extra ventilation during 15 min recovery period (E.V. rec., l./min). Ventilatory volumes have been expressed for simplicity at ambient temperature and pressure, saturated with water vapour (ATPS). At the room temperatures prevailing in these experiments, volumes at body temperature and pressure, saturated with water vapour (BTPS) would be 11-12% larger. The expired air was collected in a Douglas bag during the final minute of exercise, and samples analysed (for oxygen and carbon dioxide concentration) on a Scholander apparatus, so that the oxygen consumption and CO₂ output could be calculated.

Heart rates were measured from a standard electrocardiogram (lead 1) taken during the last minute of the initial rest period, and at 0, 1, 2, 3, 4, 5 and 15 min after exercise. Individual tracings were measured over two complete respiratory cycles to avoid problems from sinus arrhythmia. The six readings obtained 0 - 5 min after exercise were summed to give an overall index of performance in the early post-exercise period; this is described hereafter as the "pulse total".

Rectal temperatures were measured immediately before the test, at the end of the rest period, immediately after exercise, and 15 min after exercise.

RESULTS

1. Changes in ventilatory and cardiac responses to exercise over a 10 day "training" period.

The mean and S.E. of observations on 14 subjects exercising thrice daily for 15 min at a constant rate of 125 watts (746 kg.m/min) are detailed in Table 1. Almost all of the 17 parameters showed some change with repetition of the test, but in most instances the effect was greater in the first week, and even (where this was recorded) in the first four runs (Day 1 to Day 2).

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The respiratory minute volume during the initial "rest" period on the bicycle was high on Days 1 and 2, decreased markedly from Day 2 to Day 3, and thereafter showed a slow fall into the second week of the training period. The resting pulse rate was slower on Day 2 than on Day 1, but otherwise showed no consistent change over the two week period. The respiratory quotient and ventilatory equivalent for the 15th minute of exercise, and the rectal temperature rise found both immediately and 15 minutes after exercise all showed a decrease in the mean value from Day 1 to Day 5, with a suggestion of further small changes in the following week; only the changes from Day 1 to Day 8 or Day 9 were statistically significant. Most of the remaining ventilatory and cardiac parameters showed a marked change from Day 1 to Day 2, an optimum performance on Day 3, 4 or 5, some loss of "training" over the weekend, and little improvement of performance during the second week. The saddle height and general posture of the subjects was carefully controlled, and no alteration of riding technique was noted during the second week. Subjective complaints such as aching or tiredness of the limbs were not reported after the second or third day of the first week, and it is therefore difficult to attribute the absence of any physiological indication of "training" over the period Day 6 - Day 10 to any physical deterioration in the subjects; in any event, the total amount of exercise per day would seem insufficient to produce such an effect. However, the psychological attitude to the tests undoubtedly changed over the 10 days. Initially, the subjects were a little apprehensive about the various procedures; over the next few days, they became first more confident, and later somewhat bored by the routine of riding.

The fall of respiratory quotient with "training" suggests that the ventilatory response to exercise was excessive on Day 1. However, there was no clear evidence that this excessive ventilation was due primarily to changes in the first minute of exercise as others (2, 3) have suggested (See Fig.1). The decrease of exercise ventilation with "training" was brought about entirely by a decrease of respiratory rate in week 1, with no change of tidal volume. "Training" also produced a decrease in the "oxygen debt", as evidenced by the fall in ventilation for the period 0-15 min after exercise; again the change was largest from Day 1 to Day 2, with a minimum on Day 4 (10th ride).

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2. Type of "training" regime in relation to changes of performance

(a) "Maximal" effort.

Six subjects carried out one 5 min "maximal" effort ride per day, and in all six the average rate of working for the 5 min period increased slightly over the course of the week (Table 2(a)); in 5 subjects, the improvement was more than 5 watts but at an increased ventilatory cost (E.V., l./min/watt). In the sixth subject, performance was less consistent, and the increase on the final day was marginal (1.9 watts); he showed a small decrease in the ventilatory cost of this work (-0.11 l./min/watt).

Ten subjects carried out three 5 min "maximal" efforts per day. In none of these ten was the improvement in work output over the course of the week greater than the best results obtained with one ride per day; the average increase of performance for the second group was smaller than for the first, the effort of 3/10 subjects actually deteriorating over the course of the week. As in the previous group, in all subjects except one where work output increased, there was a disproportionate increase in the ventilatory cost of this effort. The respiratory minute volume during these tests was 60-80 l./min ATPS, compared with 30-55 l./min ATPS in the sub-maximal tests, and the average ventilatory cost for the group (0.63 l./min/watt at work rate of 150.3 watts), as expected (4, 5, 6) is in striking contrast with the figure for submaximal work (Table 2(b), 0.34 l./min/watt at work rate of 125 watts).

The heart rate in recovery showed an increase with rate of working in 3/4 subjects over the week of "training"; in the fourth, it was identical with the value for the first day despite an increase in the rate of working.

The last two subjects (marked by asterisk) showed a considerable increase in work output over the week, despite regular "training" for other competitive sports (Table 2(a), (ii)).

(b) Constant effort of 125 watts.

In 36/45 subjects given 15 min runs, there was a reduction in total ventilation per watt, and in 39 a reduction in extra ventilation during the recovery period over the course of the week (Table 2(b), (i)); both changes were highly significant

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($P < 0.001$). In most subjects, the major change occurred from Day 1 to Day 2, but the difference between readings on Day 1 and Day 5 has been taken as a measure of the total "training" achieved.

The recovery pulse rate also decreased considerably from Day 1 to Day 2; there were smaller decreases on Days 3 and 4, and an increase on Day 5 in 33/45 subjects. The decrease of pulse rate from Day 1 to Day 4 has thus been taken as a second measure of the total "training"; 42/45 subjects showed a decrease from Day 1 to Day 4, and the change for the group as a whole was highly significant ($P < 0.001$). The increase from Day 4 to Day 5 was probably an end-effect similar to that seen on the final day of sequential psychomotor tests.

Ten subjects rode the bicycle for 30 min at each test. As with the 15 min rides, extra ventilation decreased sharply over the first 2 days, and then more gradually (Table 2(b), (ii)), reaching the lowest value of the series on Day 5. Recovery pulse rates decreased from Day 1 to Day 4, with a small increase on Day 5. The amount of "training", as indicated by these changes, did not differ significantly from that seen in the 15 min group, and there is thus no evidence that the 30 min rides were more effective in "training" the subjects.

(c) Constant effort of 105 watts.

The immediate post-exercise pulse rate in the two subjects tested was 142/min and 109/min respectively on Day 1. Karvonen, Kentola, and Mustala, (7) have maintained that a pulse rate of 135/min is necessary to produce any "training" effect. However, both of the present subjects showed improvements in the ventilatory and cardiac cost of exercise over the course of the week, and the changes observed were at the lower end of the range observed with 30 min rides at 125 watts.

3. Influence of initial "fitness"

(a) Effect on initial performance, Day 1

The initial resting pulse rate (Table 3) decreased progressively with increase of "fitness" grade, the mean value being 91.4/min in subjects playing no regular sport, and 71.5/min in the two subjects undergoing the most rigorous training ($0.01 > P > 0.001$). The "high" resting values in untrained subjects are in agreement with recent observations by Renbourn (8). The resting respiratory minute volume showed no significant differences with respect to initial "fitness".

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Data for 59 subjects on "fitness" and the total output of mechanical work in 5 min "maximal" effort tests showed that work output increased significantly with initial "fitness" (P for difference grade 4 to grade 1-2 ≤ 0.02), but as already noted the increase in work output was achieved at a disproportionate ventilatory cost; there was thus no clear relationship between "fitness" and ventilation l./min/watt in "maximal" effort tests.

In tests where a constant rate of working was maintained, the grade of "fitness" was closely related to both the ventilatory cost of the work (l./min/watt) and the cardiac response (pulse total 0-5 min after exercise and pulse rate 15 min after exercise); for all three parameters the difference between the group of fitness grade 4 and the group of fitness grade 2 was highly significant ($P < 0.001$).

(b) Effect on amount of "training" achieved

The detailed course of ventilation in 11 subjects with no previous "training", and playing no regular sport, is illustrated during exercise (constant effort 125 watts) and recovery on Day 1 and Day 5 (Fig. 1(a)). On Day 5, the respiratory minute volume was larger than on Day 1 during the first few minutes of exercise, but a plateau of ventilation was reached earlier and at a lower level than on Day 1. At all stages during recovery, ventilation was less on Day 5 than on Day 1. The corresponding ventilation curves for a group of 9 subjects undergoing regular "training" for other sports (Fitness grade 1 or 2) were in some respects very similar (Fig. 1(b)); however, if calculated in terms of extra-ventilation, the effect of "training" was smaller in the "trained" than in the "untrained" men. The difference between "trained" and "untrained" subjects was more obvious when pulse rates for the 15 min following exercise were compared (Fig. 2); throughout the period of observation, the pulse rate was slower in the "trained" group than in the "untrained", and the improvement of pulse rate from Day 1 to Day 4 was also smaller in the "trained" group.

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Further data on the amount of "training" achieved in relation to fitness grade is summarized in Table 4. Improvements in total work output (maximal effort tests), total extra ventilation (1./min/watt, constant effort tests) and extra ventilation during the first 15 min of recovery (1.min ATPS, constant effort tests) were unrelated to fitness grade. On the other hand, the decrease in pulse totals for the first 5 min of recovery, and to a lesser extent the decrease in pulse rate 15 min after exercise, did vary with fitness grade, the largest improvement from Day 1 to Day 4 being seen in subjects who were initially "unfit".

(c) Influence of previous cycling experience

Nine subjects, initially "unfit", had been long distance cyclists (> 60 miles/day) six months or more prior to the tests. The improvement of pulse rate from Day 1 to Day 4, in this group did not differ significantly from that found in 14 subjects, initially equally "unfit", but with no previous experience of long distance cycling.

	Previous experience of long distance cycling	No previous experience of long distance cycling
Δ Pulse total 0 - 5 min recovery, Day 1 → Day 4 (constant effort, 125 watts).	-93 ± 27 (9)	-109 ± 13 (14)
Δ Pulse 15 min after exercise, Day 1 → Day 4 (constant effort, 125 watts).	-16.2 ± 3.6	-12.6 ± 3.3

Ten subjects were riding short distances at the time of the tests, but again this was without influence on the improvement in pulse rate from Day 1 to Day 4.

4. The influence of personality type

(a) Resting ventilation and pulse rate

Although the resting ventilation on Day 1 tended to be less in the "anxious" subjects, and greater in the "hysterical" subjects than in those classed as "normal", these differences were not statistically significant (Table 5). Any difference

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between the "anxious" and the "hysterical" subjects on Day 1 seemed related largely to a difference in adjustment of the individual to the experimental apparatus; the ratio resting ventilation 0 - 5 min/resting ventilation 6 - 15 min was 1.163 ± 0.027 for the "anxious" subjects, but only 1.071 ± 0.021 for the "hysterical" subjects ($\Delta = 0.091 \pm 0.034$, $0.02 > P > 0.01$).

The resting pulse rate was also high on Day 1 in the "hysterical" subjects (significance of difference from "normal" group $0.1 > P > 0.05$), but was normal in the "anxious", "psychopathic", and extravert subjects; this difference was largely abolished from Day 1 to Day 4, 5/7 "hysterical" subjects but only 3/10 "anxious" subjects showing a decrease of resting pulse rate over this period.

(b) Effect on performance for Day 1, and on amount of "training" achieved

In the "maximal effort" experiments, the average performance on Day 1 bore little relation to personality type (Table 6). However, the subjects with the normal personality showed the greatest improvement in performance from Day 1 to Day 5, the difference from "hysterical" subjects ($\Delta 5.30 \pm 2.62$ watts, $P \leq 0.05$) and from "psychopathic" subjects ($\Delta 4.40 \pm 2.08$ watts, $0.05 > P > 0.02$) being particularly marked.

In the experiments with a constant work rate of 125 watts, the response of "normal" subjects to training was a decrease in the ventilatory cost of this effort; whether measured as total extra ventilation (l./min/watt) or extra ventilation during the first 15 min after exercise (Table 6). In subjects with an "anxious" personality type the cost of work on Day 1 tended to be smaller than normal, and the decrease of cost from Day 1 to Day 5 was correspondingly less. In the "hysterical" subjects, on the other hand extra ventilation during the recovery period tended to be large on Day 1, and there was a large average improvement from Day 1 to Day 5; some subjects in this group had not regained the initial resting level of ventilation even 15 min after the end of exercise.

Pulse rates also tended to be higher than normal in the "hysterical" group of subjects, but differences were less marked than for ventilation.

Although there were differences of "fitness" (on the arbitrary scale) between the five personality groups (Table 7), it was not possible to attribute the effects described above to differences of "initial fitness"; on the contrary some of the lowest ventilation rates in "anxious" subjects were seen in subjects who were not taking part in any athletic sports, and the hysterical subject with the largest ventilation played football regularly, with two training sessions each week.

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DISCUSSION

1. Changes in Performance with "training"

With many forms of standard exercise such as treadmill walking (9, 10) and the Harvard pack test (11), a part of the improvement in performance when the task is repeated at short intervals can be attributed to "learning" (Oxford English Dictionary "Knowledge got by study"), the subjects discovering methods of reducing the mechanical work necessary to carry out the task. The possibility of such "learning" is small on the bicycle ergometer if saddle height and the position of the subject's feet on the pedals are controlled. Any improvement of maximal performance, or bettering of physiological state at a constant level of performance must thus indicate either "training" (O.E.D. "bringing athlete to physical efficiency") or "habituation" (O.E.D. "becoming accustomed to"). The improvement of physical efficiency seen with "training" may in turn reflect better adjustment of the respiratory and circulatory systems to the metabolic requirements of exercise, or an increase in the mechanical efficiency of the leg muscles so that the same amount of work is performed at a lower metabolic cost. "Habituation" may lead to greater physical efficiency if subjects show an initial tendency to hyperventilation and tachycardia; both the comments of the subjects and the change in respiratory quotient with repetition of the tests suggest that "habituation" played some part in the improvements of performance found in the present experiments.

On general grounds, one might anticipate that changes in performance with "habituation" would be related fairly closely to personality. "Training" should be less influenced by subjective factors, providing that personality is adequate to carry out the required course of vigorous exercise.

2. Physiological Indices of Training

(a) "Maximal effort" tests

"Maximal effort" tests are commonly criticised on the grounds of (i) difficulty in assessing motivation, and (ii) their short duration, with consequent failure to achieve a steady state. The present experiments show that difficulty is also created by a steep increase in the ventilatory cost of the final 20 watts of external work; at a rate of 125 watts, extra ventilation is no more than

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0.2 - 0.3 l./min/watt, but it increases to 0.5 - 0.8 l./min/watt in "maximal effort" tests (140 - 160 watts). Thus a decrease in the ventilatory cost of a given effort during "training" may be obscured by a small increase in the amount of external work performed, and conversely a decrease of working capacity may in fact be masked by a large fall in the ventilatory cost of exercise. The commonly adopted indices such as exercise pulse rate and ventilation cannot be used, and the only valid measures of changes in performance with training or incapacitation are the output of work achieved, and the physiological state prior to exercise.

The fact that with repetition of the test, ventilatory and cardiac efforts were often increased to achieve a greater work output suggests that "habituation" to the unpleasant sensations of "maximal" work played a large part in the improvement of performance. Subjectively, 9/16 men thought the rides easier with repetition, and only 2/16 found them harder. Limitation of performance by unpleasant sensations would explain why the greatest improvement over the week of "training" was seen in subjects with a "normal" type of personality, and why some subjects actually showed a deterioration in "maximal" work output. "Maximal effort" tests seem critically dependent on the full co-operation of the subject, and inevitably measure not only the physiological, but also the psychological factors restricting performance in a given experimental situation.

(b) Constant effort tests

The majority of the physiological parameters showed some change over the period of study, usually in the direction of an improvement of physical state.

A greater efficiency of ventilatory exchange was shown by a 10% reduction in the ventilatory equivalent for oxygen. This improvement did not completely parallel the slowing of respiratory rate, and a better adjustment of ventilation/perfusion ratios in the lungs must also have contributed to this change.

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The efficiency of the leg muscles was also apparently increased. Taking figures for Day 1 and Day 5 from Table 1, a metabolic balance sheet would read as follows:-

	<u>Day 1</u>	<u>Day 5</u>
Total oxygen consumption (l./min)	2.29	2.09
" resting oxygen cons.(l./min)	0.3	0.3
" oxygen cost of ventilation (l./min at 1 ml./l)	0.039	0.038
Oxygen cost of leg work (l./min)	1.95	1.75
Respiratory Quotient	1.00	0.95
Calorific equivalent of oxygen (Cal./min)	5.05	4.98
Metabolic work (Cal./min)	9.85	8.71
Ergometer work (Cal./min)	1.785	1.785
Efficiency of ergometer work	18.1%	20.5%

It has been assumed in calculating this simple balance sheet that during the ergometer test, added oxygen consumption arises from two sources:- the internal and external work of ventilation, and the effort of the leg muscles. The efficiency quoted is thus an overall value for the body considered as a working machine, and includes postural components from muscles not immediately concerned with movement of the bicycle pedals. The change in efficiency from Day 1 to Day 5 represent either improved postural adjustment ("learning") or a true increase in efficiency of individual leg muscles ("training").

Changes of heart rate were in general larger and more consistent than the ventilatory changes, probably because more factors combined to reduce heart rate with repetition of the tests. The metabolic requirements of both "leg" and respiratory muscles were reduced, and there was a corresponding reduction of metabolic heat production; finally, the efficiency of the cardiovascular system (perfusion equivalent for oxygen) may also have improved. Because it integrates a wide variety of adjustments, the pulse rate is probably a better indicator of physical state than measurements of ventilation; this conclusion is borne out by observations of the effect of initial "fitness" on both performance on Day 1, and on the improvement in performance from Day 1 to Day 4.

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As in the "maximal" exercise tests, many of the adjustments during the "training" period seem due to "habituation". A relative hyperventilation occurred on Day 1, as shown by the high respiratory quotient on this day; the decrease of respiratory quotient from Day 1 to Day 8 or 9 (7 and 6% respectively) corresponded approximately with the decrease of respiratory minute volume observed during constant sub-maximal exercise, and this change can thus be attributed entirely to "habituation". Any "learning" effects would presumably be greatest while exercise was being performed, and since changes during exercise can be accounted for by "habituation", "learning" can have little influence on the results obtained; this finding was anticipated from the rigid control of the pattern of working. During the period of recovery from exercise, changes were in general larger than the 6 - 7% predicted for "habituation" (extra ventilation for 15 min following exercise 19% on Day 8, and 35% on Day 9; pulse total 0 - 5 min after exercise 10% on Day 8 and 12% on Day 9; pulse rate 15 min after exercise 7% on Day 8, and 9% on Day 9). Learning is unlikely to be apparent only after exercise, and the improvement in recovery rate shown by these figures seems in part a manifestation of true "training".

3. Optimum regime for training

Previous workers have shown that performance of a specific task can be improved to some extent by general exercise such as marching (12), or the playing of lacrosse (13). The present experiments support this conclusion. If the best index of "training" (pulse total 0 - 5 min after exercise) is taken, subjects in regular training for other sports show a lower total on Day 1, and a smaller improvement from Day 1 to Day 4 (presumably because there is less scope for improvement of bodily efficiency); the change from Day 1 to Day 4 in subjects classed initially as fitness grades 1 and 2 is indeed no more than the 6% habituation effect described above.

If reliance is placed upon general measures of "training", these must be pursued vigorously; it is not unknown for performance to decline during the period of observation (11, 14). When the subject is trained for the specific form of exercise on which performance is to be assessed, the optimum duration and rate of activity probably varies with the cardio-respiratory load imposed by the task. Karvonen et al. (7) exercised men on a treadmill for 30 min periods 4 - 5 times per week, and they found that an exercise pulse rate of 135/min was

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necessary to improve performance. Fletcher (15) also believed a pulse rate of this order was needed for improved performance of a stop test. On the other hand, Durnin et al. (12) found some training was occurring in men walking 20 km/day, and in their experiments the pulse rate was no more than 120/min. In most of the present experiments, the pulse rate at the end of exercise was in excess of 135/min, but in one of the two experiments at an output of 105 watts, some improvement of performance was seen despite a pulse rate of only 109/min at the end of the exercise.

With "maximal" effort rides, the improvement of performance was not hastened by changing from one to three rides per day; the most co-operative subjects of each group achieved the highest performance on Day 4 or Day 5. With the constant effort rides, the main improvement in pulse total occurred from Day 1 to Day 3, and this improvement was actually less for subjects performing 30 min rides than for subjects riding for 15 min periods. The deterioration of performance during the second week may reflect "negative habituation", as the subjects became bored with the task. It is unlikely that a true loss of physical efficiency due to excessive exercise would first appear after the weekend break, as few of the subjects spent their free period in energetic pursuits.

4. The influence of personality

No relationship could be demonstrated between personality and extra-ventilation or pulse rate in the "maximal effort" experiments. This may be due partly to the alinear relationship between work output and cardio-respiratory load. "Normal" subjects achieved a higher rate of working than other personality types, and this would tend to obscure the relationship between hyperventilation and personality.

With the subjects performing longer periods of constant sub-maximal work, some trend with personality was apparent, although with the number of subjects seen it did not have great statistical significance. Both at rest and during exercise, "hysterical" subjects showed a greater respiratory minute volume and a faster pulse rate than normal, and habituated more rapidly with repetition of the experiment; "anxious" subjects showed a smaller initial response than normal, and habituated less rapidly with repetition of the tests. Such "habituation" can occur in subjects already in "training", and in specific instances the change of ventilation can equal or exceed that produced by training.

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Personal variation is well recognised as one of the main factors limiting further advance in the interpretation of respiratory and cardiac measurements made on the individual (17). The present method of classifying personality types is admittedly crude, but the results are of sufficient promise to suggest that the sub-division of psychiatrically "normal" subjects according to personality type may ultimately be a useful means of reducing personal variation in physiological data. Further, excessive ventilatory work can itself limit performance, and for this reason personality and the psychological approach to successive work periods can be significant determinants both of initial working capacity and also of the response to "training" regimes and to incapacitating agents.

5. The testing of physical incapacitation

From the military standpoint, physical incapacitation may show itself in three ways. Firstly, the maximum capacity for a short period of work may be significantly reduced. Secondly, work that is normally sub-maximal may be performed with such a reduction in efficiency that it, too, exceeds the tolerance limit when the effort is prolonged. Thirdly, sub-maximal work may be performed at reduced efficiency, and while remaining within the capacity of the individual, may give rise to general harassment.

The first type of incapacitation is readily measured by "maximal" effort tests. Performance is not far from maximum on Day 1, and a "plateau" of performance against which the effect of an agent can be tested is obtained if the rides are repeated only once a day for five days. Any change in the "maximal" rate of working following administration of the incapacitating agent is due to a combination of both physiological and psychological factors, but some assessment of the importance of the latter can be obtained by comparing terminal pulse rates on test and control days.

The end-point of "endurance" is one of the least satisfactory measures of performance, and for this reason it is not usually practicable to measure the second type of incapacitation directly; as with the third type, it is more conveniently and accurately assessed in terms of a decrement in physiological efficiency. A wide variety of parameters, ventilatory and cardiac, must be measured; although many of these reach a minimum in the first week, results are more stable during the second week of testing, and this is thus the optimum time to examine the effects of an incapacitating agent.

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TABLE 1

The Physiological pattern of "training" over a 10 day period

All values mean \pm S.E. of observations on 14 men riding thrice daily at effort of 125 watts for 15 min

Parameter	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Resting Ventilation (0-5 min, 1./min ATPS)	13.07 ± 0.87	13.36 ± 0.89	13.11 ± 0.75	12.63 ± 0.64	12.74 ± 0.66	11.66 ± 0.49	11.64 ± 0.51	12.27 ± 0.82	11.66 ± 0.53	11.79 ± 0.63
Resting ventilation (6-15 min) 1./min ATPS	11.93 ± 0.92	12.32 ± 0.83	10.93 ± 0.46	10.86 ± 0.67	10.72 ± 0.42	9.66 ± 0.45	10.16 ± 0.54	10.68 ± 0.52	10.36 ± 0.46	10.29 ± 0.38
Extra ventilation 0-1 min exercise (1./min ATPS)	15.23 ± 1.15	14.16 ± 1.35	13.94 ± 1.03	14.30 ± 1.39	17.09 ± 0.79	16.71 ± 0.98	18.14 ± 1.08	16.71 ± 1.11	18.74 ± 1.32	18.60 ± 0.95
Extra ventilation 0-15 min exercise (1./min ATPS)	39.3 ± 2.3	37.4 ± 2.2	35.6 ± 1.9	36.7 ± 1.9	37.6 ± 1.5	38.4 ± 1.4	38.4 ± 1.6	37.3 ± 1.4	37.2 ± 1.3	38.1 ± 1.4
Extra ventilation 0-15 min after exercise (1./min ATPS)	6.69 ± 0.85	4.76 ± 0.84	3.61 ± 0.67	3.29 ± 0.46	4.01 ± 0.57	3.73 ± 0.57	4.48 ± 0.33	5.39 ± 0.79	4.36 ± 0.46	3.63 ± 0.35
Total Extra ventilation (1./min/watt)	0.360 ± 0.022	0.333 ± 0.022	0.307 ± 0.018	0.315 ± 0.017	0.329 ± 0.014	0.323 ± 0.011	0.334 ± 0.012	0.331 ± 0.009	0.336 ± 0.013	0.326 ± 0.007

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TABLE 1 (Cont'd.)

Parameter	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Respiratory rate (15th min exercise)	29.5 ±3.5				25.1 ±1.4		24.8 ±1.7	25.6 ±2.5	26.3 ±1.8	
Tidal volume (15th min exercise)	1869 ±127				1856 ±77		1949 ±101	1844 ±104	1760 ±87	
Oxygen Cons. (ml. STPD/min, 15th min exercise)	2293 ±117				2091 ±41		2178 ±37	2178 ±56	2146 ±41	
CO ₂ output (ml. STPD/min, 15th min exercise)	2295 ±142				2029 ±65		2078 ±45	2009 ±58	2025 ±47	
Ventilatory equivalent	2.33 ±0.09				2.18 ±0.08		2.16 ±0.08	2.10 ±0.06	2.13 ±0.05	
Respiratory Quotient	1.00 ±0.02				0.95 ±0.02		0.96 ±0.02	0.93 ±0.02	0.94 ±0.01	
Resting pulse	86 ± 5	75 ± 3	79 ± 3	81 ± 3	79 ± 4	84 ± 4	79 ± 4	83 ± 3	84 ± 3	83 ± 2

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TABLE 1 (Cont'd.)

Parameter	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Pulse total 0-5 min after exercise	762 +28	683 +28	672 +26	644 +26	660 +27	714 +19	692 +20	684 +25	674 +18	674 +20
Pulse 15 min after exercise	107+4	94+3	92+4	92+5	92+4	101+3	101+4	100+4	98+4	95+3
Rise of Rectal temperature immediately after exercise (°F)	0.98 +0.20				0.59 +0.09		0.64 +0.10	0.54 +0.09	0.69 +0.13	
15 min after exercise (°F)	1.03 +0.20				0.66 +0.10		0.45 +0.09	0.50 +0.09	0.43 +0.08	

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TABLE 2

Effect of type of regime on "training" achieved

(a) "Maximal effort"

(i) one 5 min ride per day

Total Output of Work (watts)					Extra ventilation (l./min/watt)					Pulse total after exercise				
Day 1	Day 2	Day 3	Day 4	Day 5	Δ 1 \rightarrow 5	Day 1	Day 5	Δ 1 \rightarrow 5		Day 1	Day 4	Day 1	Day 4	Δ 1 - 4
127.4	118.3	126.8	122.0	128.5	+ 1.1	0.65	0.54	-0.11						
145.0	144.9	151.9	151.3	151.0	+ 6.0	0.47	0.71	+0.24						
142.2	145.1	148.2	146.9	147.4	+ 5.2	0.67	0.69	+0.02						
150.9	152.9	154.8	152.6	156.5	+ 5.6	0.56	0.65	+0.09						
144.4	150.5	156.1	157.7	157.1	+12.7	0.72	0.79	+0.07						
140.7	143.0	147.5	149.6	152.1	+11.4	0.49	0.77	+0.28						
141.7	142.5	147.6	146.7	148.8	+ 7.1	0.59	0.69	0.10						
± 3.5	± 5.1	± 4.4	± 5.1	± 4.6	± 1.7									

(ii) three 5 min rides per day

Total Output of Work (watts)					Extra ventilation (l./min/watt)					Pulse total after exercise				
Day 1	Day 2	Day 3	Day 4	Day 5	Δ 1 - 5	Day 1	Day 5	Δ 1 - 5		Day 1	Day 4	Day 1	Day 4	Δ 1 - 4
142.3	150.6	148.8	151.8	149.7	+ 7.4	0.74	0.60	-0.4						
159.8	158.9	158.7	157.7	159.3	- 0.5	0.59	0.61	+0.02						
158.2	157.7	157.8	157.1	156.7	- 1.5*	0.70	0.59	-0.11						
145.3	147.4	148.8	151.3	150.2	+ 4.9	0.56	0.61	+0.05						
153.3	149.1	147.3	149.0	149.5	- 3.8*	0.80	0.71	-0.09						
156.4	154.4	155.6	157.1	157.2	+ 0.8	0.65	0.71	+0.06						
143.1	145.1	148.3	151.3	149.4	+ 6.3	0.59	0.60	+0.1						
144.6	144.7	148.3	147.7	147.4	+ 2.8	0.73	0.73	0						
150.4	152.1	153.5	154.7	155.9	+ 5.5*	0.50	0.64	+0.14						
150.0	153.4	154.2	155.9	161.5	+11.5*	0.41	0.66	+0.25						
150.3	151.3	152.1	153.4	153.7	+ 3.4	0.63	0.65	+0.02						
± 2.0	± 1.6	± 1.4	± 1.1	± 1.6	± 1.5					852	940	125	133	+8
										842	872	110	115	+5
										845	858	117	124	+7
										673	673	89	88	-1
										803	846	110	115	+5

*Subjects "training" regularly for other sports.

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TABLE 2(Contd'd)

(b) Constant output, 125 watts

(i) Three 15 min rides/day: detailed values for first 10 subjects, mean and S.E. for - 45 subjects

Total Extra ventilation/watt					Extra ventilation during Recovery (l./min)						
Day 1	Day 2	Day 3	Day 4	Day 5	1 Δ 5	Day 1	Day 2	Day 3	Day 4	Day 5	1 Δ 5
0.29	0.33	0.32	0.26	0.27	-0.02	4.9	4.6	2.8	1.7	2.4	-2.5
0.24	0.19	0.17	0.18	0.19	-0.05	4.2	0.0	0.5	-0.3	-0.3	-4.5
0.16	0.26	0.21	0.20	0.16	-0.00	3.3	10.7	3.9	4.1	0	-3.3
0.27	0.29	0.31	0.31	0.29	+0.02	3.0	3.8	3.4	4.7	3.7	+0.7
0.31	0.31	0.32	0.33	0.30	-0.01	4.7	3.8	5.1	5.2	4.3	-0.4
0.28	0.27	0.29	0.29	0.26	-0.02	2.1	1.8	2.5	3.0	0.1	-2.0
0.24	0.22	0.24	0.23	0.27	+0.03	4.3	2.6	4.9	3.7	6.1	+1.8
0.41	0.30	0.32	0.31	0.33	-0.08	6.1	2.6	2.8	2.3	3.4	-2.7
0.19	0.23	0.22	0.22	0.23	+0.04*	0.9	1.5	0	-1.4	0	-0.9*
0.40	0.40	0.42	0.37	0.38	-0.02	7.2	6.0	7.0	5.5	5.5	-1.7
0.340 \pm 0.012	0.325 \pm 0.011	0.311 \pm 0.010	0.308 \pm 0.009	0.312 \pm 0.009	-0.028 \pm 0.007	5.95 \pm 0.40	4.85 \pm 0.46	4.02 \pm 0.34	3.63 \pm 0.26	3.55 \pm 0.31	-2.40 \pm 0.35

*Subject "training" regularly for other sports.

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TABLE 2(Cont'd.)

(b) Constant output, 125 watts (Cont'd.)

Recovery pulse rate (0 ~ 5 min total)						15 min recovery pulse rate					
Day 1	Day 2	Day 3	Day 4	Day 5	Δ 1 \rightarrow 4	Day 1	Day 2	Day 3	Day 4	Day 5	Δ 1 \rightarrow 4
823	791	691	697	754	-126	110	111	95	87	104	-23
689	590	634	595	610	-94	97	81	82	79	87	-18
677	702	657	632	610	-45	87	108	96	90	91	+3
657	593	612	567	596	-90	103	87	91	78	87	-25
803	680	690	680	692	-123	108	91	107	97	99	-11
726	665	625	625	627	-101	105	88	90	83	92	-22
874	732	711	708	782	-166	132	108	99	95	122	-37
757	638	619	616	644	-141	102	97	86	89	90	-13
514	575	576	534	570	+20*	74	81	78	72	85	-2*
1012	944	884	820	895	-192	152	128	120	115	127	-37
765	712	695	672	693	-93	106.0	98.5	95.4	93.4	96.9	-12.6
± 16	± 14	± 13	± 13	± 13	± 9	± 2.8	± 2.1	± 1.8	± 2.2	± 2.4	± 2.2

*Subject "training" regularly for other sports.

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TABLE 2(Cont'd.)

(11) Three 30 min rides/day

Total Extra ventilation/watt						Extra ventilation during recovery (l./min)					
Day 1	Day 2	Day 3	Day 4	Day 5	Δ 1 \rightarrow 5	Day 1	Day 2	Day 3	Day 4	Day 5	Δ 1 \rightarrow 5
0.26	0.27	0.25	0.24	0.23	-0.03	6.3	9.4	7.2	5.1	2.6	-3.7
0.29	0.28	0.26	0.27	0.26	-0.03	3.3	3.7	3.5	3.1	3.8	+0.5
0.27	0.28	0.26	0.24	0.23	-0.04*	2.5	2.6	2.4	2.6	2.5	0.0*
0.26	0.23	0.19	0.17	0.14	-0.12*	11.2	3.2	-0.9	-0.9	3.8	-15.0*
0.25	0.25	0.22	0.22	0.24	-0.01	2.1	3.5	3.1	2.4	3.2	+1.1
0.36	0.34	0.33	0.34	0.32	-0.04	5.0	5.6	4.0	3.5	4.2	-0.8
0.31	0.29	0.30	0.32	0.30	-0.01	7.0	3.1	4.3	6.2	6.8	-0.2
0.28	0.31	0.28	0.27	0.29	+0.01*	4.7	11.1	3.3	4.3	3.2	-1.5*
0.30	0.30	0.31	0.31	0.32	+0.02	4.4	7.6	8.5	4.1	4.5	+0.1
0.30	0.30	0.30	0.32	0.29	-0.01	3.1	3.8	3.4	3.7	2.0	-1.1
0.288 ± 0.010	0.285 ± 0.013	0.270 ± 0.013	0.270 ± 0.017	0.262 ± 0.017	-0.026 ± 0.012	5.0 ± 0.9	5.4 ± 0.9	3.9 ± 0.8	3.4 ± 0.6	2.9 ± 0.9	-2.1 ± 1.5

*Subject "training" regularly for other sports.

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TABLE 2(Cont'd.)

Recovery pulse rate (0 - 5 min total)						15 min recovery pulse rate					
Day 1	Day 2	Day 3	Day 4	Day 5	Δ 1 \rightarrow 4	Day 1	Day 2	Day 3	Day 4	Day 5	Δ 1 \rightarrow 4
-	-	-	-	-	-	90	89	83	72	78	-18
-	-	-	-	-	-	117	86	75	98	87	-19
745	813	706	687	686	-58*	101	112	97	99	98	-2*
609	525	563	573	587	-35*	95	80	79	86	87	-9*
769	739	706	673	671	-96	99	109	100	93	92	-6
890	823	787	754	738	-138	127	118	108	101	101	-26
734	672	684	691	682	-41	107	90	94	89	96	-18
649	650	607	639	653	-10*	85	80	77	84	84	-1*
736	730	717	709	714	-27	77	101	94	98	108	+21
765	741	725	700	739	-65	105	99	103	98	105	-7
737	712	687	678	684	-59	100	96	91	92	94	-8.5
+30	+30	+22	+17	+16	+14.5	+4.7	+4.3	+3.7	+2.9	+3.1	+4.2

*Subjects "training" regularly for other sports.

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TABLE 2(Cont'd.)

(c) Constant output 105 watts. Three 30 min rides/day

Total extra ventilation / watt					Extra ventilation during recovery (l./min)						
Day 1	Day 2	Day 3	Day 4	Day 5	Δ 1 \rightarrow 5	Day 1	Day 2	Day 3	Day 4	Day 5	Δ 1 \rightarrow 5
0.23 0.18	0.21 0.18	0.20 0.16	0.19 0.15	0.21 0.16	-0.02 -0.02	2.8 1.8	1.7 1.3	1.1 1.5	0.4 -0.8	1.2 2.8	-1.6 +1.0

Recovery pulse rate (0 - 5 min total)					15 min recovery pulse rate						
Day 1	Day 2	Day 3	Day 4	Day 5	Δ 1 \rightarrow 5	Day 1	Day 2	Day 3	Day 4	Day 5	Δ 1 \rightarrow 5
700 600	705 549	663 619	671 561	721 643	-29 -39	107 85	100 78	106 90	103 77	101 85	-4 -8

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TABLE 3

Effect of initial "fitness" on performance for Day 1
Mean, S.E., and number of observations

Parameter	Fitness Grade			
	4	3	2	1
Resting ventilation 6th - 15th min on bicycle ergometer (l./min, ATPS)	11.23 ± 0.46 (45)	11.93 ± 0.69 (15)	11.42 ± 1.45 (10)	14.13 (3)
Resting pulse rate 14th - 15th min rest on bicycle ergometer.	91.4 ± 2.5 (32)	78.9 ± 3.2 (12)	72.7 ± 5.4 (7)	71.5 (2)
Total output of mechanical work (watts) - 5 min maximal effort	150.5 ± 1.7 (31)	152.0 ± 2.5 (20)	158.2 ± 3.2 (8)	
Total extra ventilation (l./min/watt) - 15 and 30 min rides, 125 watts.	0.350 ± 0.013 (34)	0.313 ± 0.022 (12)	0.294 ± 0.021 (8)	0.26 (3)
Pulse total, 0 - 5 min after exercise at 125 watts.	813 ± 15 (32)	710 ± 21 (12)	669 ± 25 (7)	563 (2)
Pulse rate, 15 min after exercise at 125 watts.	112 ± 3 (32)	97 ± 3 (12)	93 ± 7 (7)	85 (2)

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TABLE 4

Effect of initial "fitness" on "training" achieved
Mean, S.E., and number of observations

Parameter	Fitness Grade			
	4	3	2	1
Δ Total output of work Day 1 \rightarrow Day 5 (watts) in maximal effort tests.	$+3.9 \pm 1.1$ (27)	$+2.0 \pm 1.8$ (18)	$+5.1 \pm 2.3$ (8)	
Δ extra ventilation Day 1 \rightarrow Day 5 (l./min/watt). Constant effort 125 watts.	-0.028 ± 0.009 (34)	-0.029 ± 0.010 (12)	-0.033 ± 0.018 (7)	$+0.015$ (2)
Δ extra ventilation during recovery Day 1 \rightarrow Day 5 (l./ATPS) min. Constant effort 125 watts.	-2.0 ± 0.4 (34)	-2.4 ± 0.8 (12)	-2.7 ± 2.2 (7)	-2.3 (2)
Δ pulse total 0 - 5 min after exercise, Day 1 \rightarrow Day 4. Constant effort 125 watts.	-105 ± 11 (32)	-80 ± 12 (12)	-37 ± 18 (17)	-46 (2)
Δ pulse rate 15 min after exercise Day 1 \rightarrow Day 4. Constant effort 125 watts.	-13.3 ± 2.4 (34)	-10.0 ± 3.7 (12)	-6.9 ± 7.1 (7)	-14.5 (2)

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TABLE 5

Relationship between personality and resting ventilating and pulse rate.
Mean, S.E., and number of observations

Parameter	Personality type				
	Normal	Anxious	Hysterical	Psychopathic	Extravert
Resting ventilation Day 1 (l./min, ATPS).	11.15 \pm 0.60 (27)	10.43 \pm 0.88 (11)	11.54 \pm 1.47 (9)	10.85 \pm 0.45 (14)	11.26 \pm 1.10 (12)
Day 5 (l.min, ATPS)	10.34 \pm 0.63 (27)	10.18 \pm 0.83 (11)	10.58 \pm 1.03 (9)	11.22 \pm 0.35 (14)	9.75 \pm 0.49 (12)
Δ Day 1 - Day 5 (l./min, ATPS)	-0.81 \pm 0.19 (27)	-0.25 \pm 0.33 (11)	-0.96 \pm 0.97 (9)	+0.37 \pm 0.29 (14)	-1.51 \pm 0.85 (12)
Ratio - Mean resting ventilation 0 - 5 min, 6 - 15 min for Day 1.	1.123 \pm 0.016 (27)	1.163 \pm 0.027 (11)	1.072 \pm 0.021 (9)	1.101 \pm 0.021 (14)	1.117 \pm 0.015 (12)
Resting pulse rate Day 1	84.4 \pm 4.1 (22)	86.3 \pm 4.2 (10)	97.1 \pm 5.9 (7)	86.3 \pm 4.1 (9)	80.4 \pm 4.1 (11)
Day 4	82.4 \pm 3.0 (22)	84.6 \pm 3.1 (10)	88.3 \pm 4.2 (7)	83.4 \pm 4.6 (9)	78.2 \pm 3.9 (11)
Δ Day 1 - Day 4	-2.0 \pm 2.7 (22)	-1.7 \pm 4.0 (10)	-8.8 \pm 6.5 (7)	-2.9 \pm 2.4 (9)	-2.2 \pm 3.0 (11)

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TABLE 6

Influence of personality type on degree of "training" achieved
Mean, S.E., and number of observations

Parameter	Personality type				
	Normal	Anxious	Hysterical	Psychopathic	Extravert
Maximal rate of working, Day 1 (watts).	152.6 ± 2.5 (19)	150.8 ± 2.1 (4)	149.2 ± 4.4 (7)	154.9 ± 2.7 (16)	150.7 ± 3.2 (5)
Day 5 (watts)	158.6 ± 2.7 (19)	153.5 ± 1.5 (4)	149.8 ± 3.7 (7)	156.4 ± 1.7 (16)	154.1 ± 1.4 (5)
Increase (Δ Day 5 - Day 1) (watts)	6.0 ± 1.9 (19)	2.7 ± 0.7 (4)	0.6 ± 1.8 (7)	1.5 ± 0.9 (16)	3.4 ± 1.7 (5)
Total extra ventilation Day 1 (1./min/watt ATPS) - constant work rate 125 watts.	0.341 ± 0.021 (19)	0.317 ± 0.027 (9)	0.337 ± 0.044 (6)	0.341 ± 0.022 (10)	0.306 ± 0.020 (11)
Day 5 (1./min/watt ATPS)	0.299 ± 0.015 (19)	0.302 ± 0.022 (9)	0.283 ± 0.033 (6)	0.322 ± 0.022 (10)	0.296 ± 0.017 (11)
Decrease Day 1 - Day 5 (1./min/watt ATPS).	-0.042 ± 0.012 (19)	-0.015 ± 0.005 (9)	-0.054 ± 0.021 (6)	-0.019 ± 0.009 (10)	-0.010 ± 0.012 (11)

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TABLE 6(Cont'd.)

Parameter	Personality type				
	Normal	Anxious	Hysterical	Psychopathic	Extravert
Extra ventilation during 15 min recovery period, Day 1 (1./min ATPS) - constant work rate 125 watts.	6.01 \pm 0.74 (19)	5.56 \pm 0.85 (9)	6.90 \pm 1.31 (6)	6.07 \pm 0.75 (10)	4.60 \pm 0.57 (11)
Day 5 (1./min ATPS)	3.54 \pm 0.50 (19)	3.87 \pm 0.56 (9)	1.72 \pm 1.21 (6)	3.90 \pm 0.49 (10)	3.55 \pm 0.65 (11)
Change Day 1 - Day 5 (1./min ATPS)	-2.47 \pm 0.53 (19)	-1.69 \pm 0.95 (9)	-5.18 \pm 2.02 (6)	-2.17 \pm 0.65 (10)	-1.05 \pm 0.47 (11)
Pulse total 0 - 5 min after exercise, Day 1 (constant work rate 125 watts).	751 \pm 29 (17)	767 \pm 30 (9)	788 \pm 61 (6)	789 \pm 21 (10)	733 \pm 29 (11)
Pulse total Day 4	661 \pm 23 (17)	666 \pm 22 (9)	702 \pm 36 (6)	697 \pm 15 (10)	660 \pm 24 (11)
Change in pulse total Day 1 - Day 4	-90 \pm 13 (17)	-101 \pm 25 (9)	-86 \pm 34 (6)	-92 \pm 19 (10)	-73 \pm 16 (11)
Pulse rate 15 min after exercise, Day 1 (constant work rate 125 watts)	104.8 \pm 4.2 (19)	106.2 \pm 5.9 (9)	110.7 \pm 10.2 (6)	103.2 \pm 3.6 (10)	102.7 \pm 4.7 (11)
Day 4	91.0 \pm 3.6 (19)	94.0 \pm 3.2 (9)	98.8 \pm 5.0 (6)	95.3 \pm 5.6 (10)	92.0 \pm 3.5 (11)
Change Day 1 - Day 4	-13.8 \pm 3.1	-12.2 \pm 6.3	-11.9 \pm 8.5	-8.9 \pm 3.9	-10.7 \pm 3.6

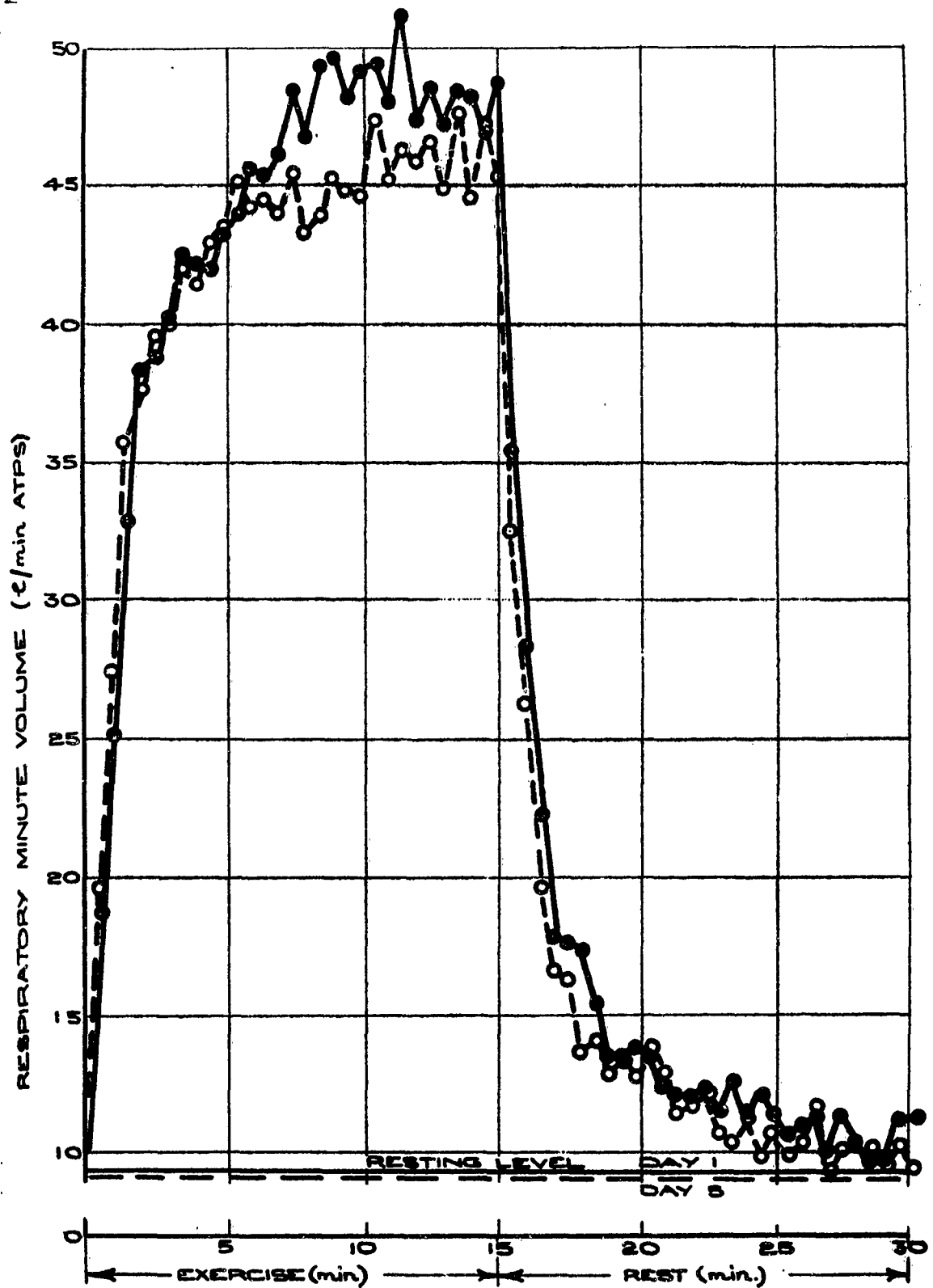
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TABLE 7

Initial "fitness" in relation to personality

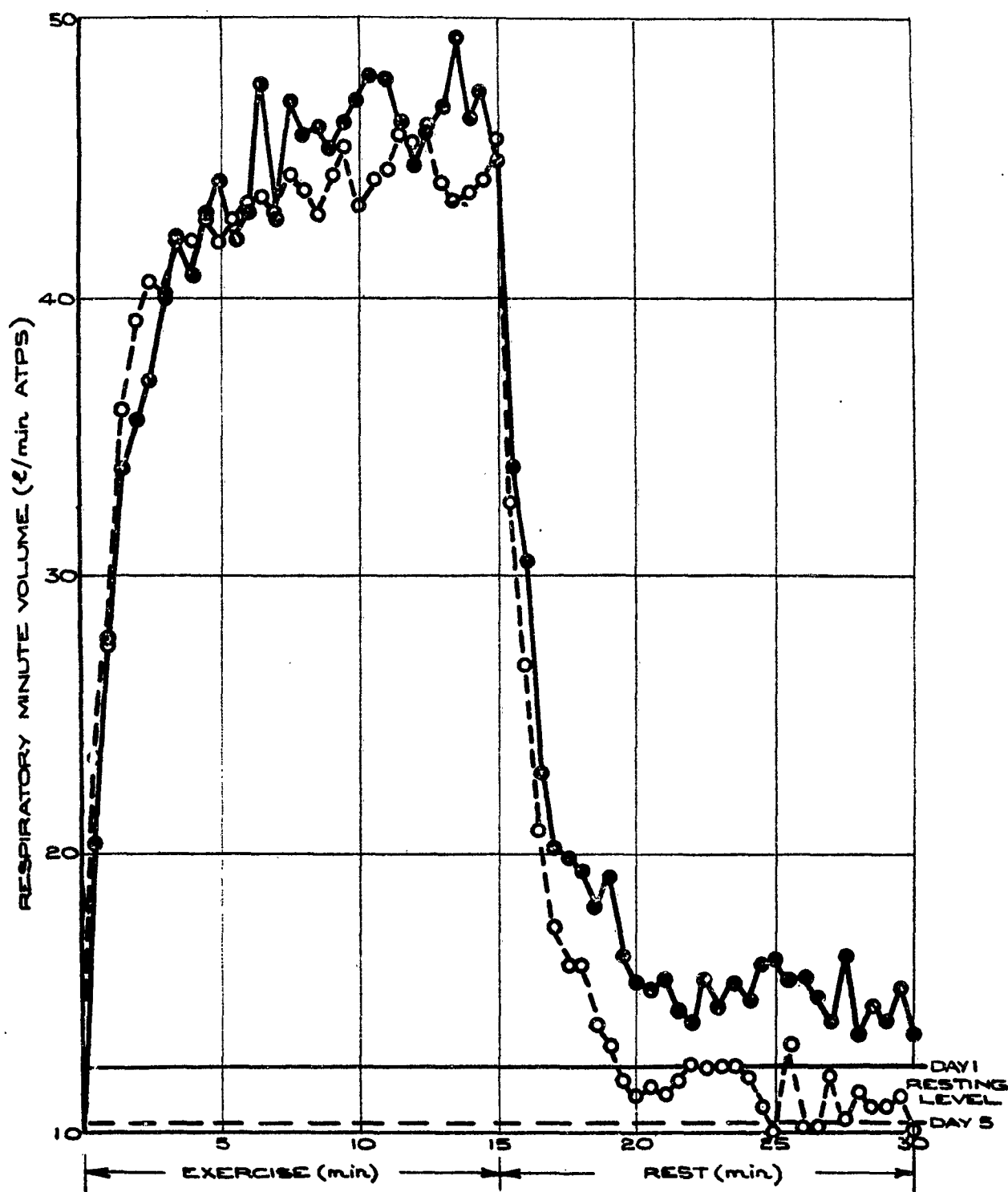
Fitness Grade	Personality type				
	Normal	Anxious	Hysterical	Psychopathic	Extravert
4	19(59.4%)	8(72.7%)	7(77.8%)	9(64.3%)	5(45.1%)
3	7(21.8%)	3(27.3%)	1(11.1%)	3(21.4%)	2(18.2%)
2	4(12.5%)	0	1(11.1%)	2(14.3%)	3(27.3%)
1	2(6.3%)	0	0	0	1(9.1%)
Total	32	11	9	14	11
Weighted "fitness" grade	3.34	3.72	3.67	3.50	3.00

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EFFECT OF "TRAINING" ON RESPIRATORY MINUTE VOLUME
OF 11 INITIALLY UNTRAINED SUBJECTS.

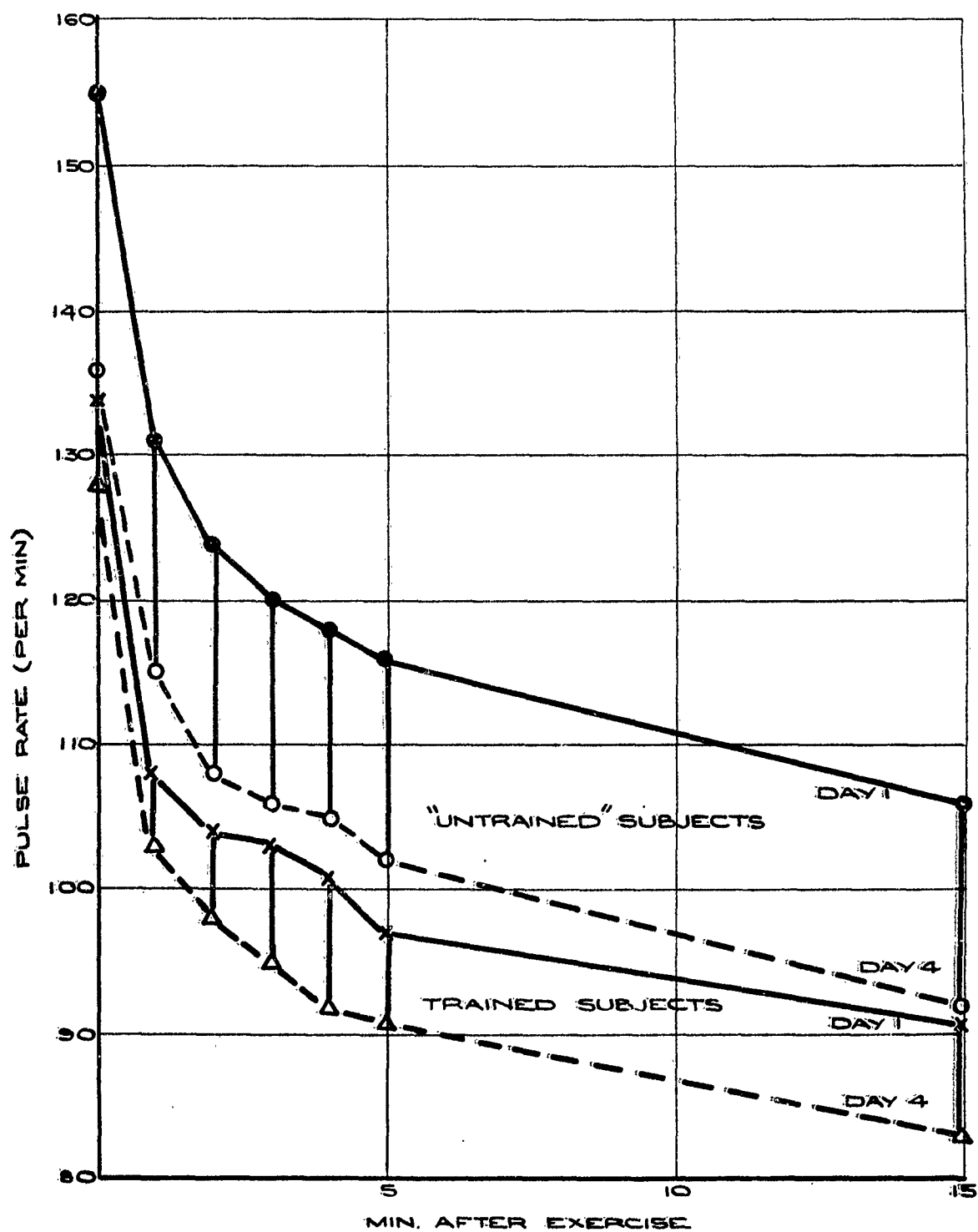
FIG. 1(a) —●— DAY 1. VENTILATION DURING AND FOLLOWING FIRST 15 MIN. RIDE AT 125 WATTS
—○— DAY 5. VENTILATION DURING AND FOLLOWING 15 MIN. RIDE AT 125 WATTS.



EFFECT OF "TRAINING" ON RESPIRATORY MINUTE VOLUME OF 9 SUBJECTS
INITIALLY IN "TRAINING" FOR OTHER SPORTS.

—●— DAY 1. VENTILATION DURING AND FOLLOWING FIRST 15 MIN. RIDE AT 125 WATTS.

FIG. 1(b) --○-- DAY 5. VENTILATION DURING AND FOLLOWING 15 TH. 15 MIN RIDE AT 125 WATTS.



PULSE RATES DURING RECOVERY FROM EXERCISE AT 125 WATTS.

(a) 11 SUBJECTS, INITIALLY "UNTRAINED."

(b) 9 SUBJECTS, INITIALLY "IN TRAINING."

FIG. 2

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APPENDIX to P.T.P. 860

The electrically-braked bicycle ergometer

The apparatus is illustrated diagrammatically in Fig.A.1. A shunt-wound car dynamo was spring-loaded onto the flywheel of a standard 23 in. frame bicycle ergometer. The internal resistance of the shunt windings was relatively constant at a little over 4 ohms. The external load consisted of two car headlights (12V, 72W and 6V, 36W) mounted in series. The power consumption of the lamps varied somewhat with filament temperature, and to overcome this difficulty, subjects were instructed at the beginning of a ride to bring the lamps to above the brilliance maintained during steady cycling. All results were thus obtained with the filaments gradually cooling. A low inertia motor and counting unit was mounted in parallel with the lights, and after calibration the counter reading for a given period could be converted to electrical work (watts). Some incentive for the subjects was provided by the variations in brilliance of the lamps, but as an additional spur to effort, a small cycle dynamo was coupled to a voltmeter on the control panel, and a series rheostat was so adjusted that the speed of any subject was apparently a little under half of maximum for the machine.

Calibration was carried out by mounting an ammeter and voltmeter in the flywheel dynamo unit, using the dynamo as a motor, and comparing the electrical work generated by the subject with the electrical power required to drive dynamo, bicycle and lights at the same speed. This method of calibration is open to some criticism, since the mechanical efficiency of the bicycle may be less when operated normally, owing to an increase of pressure on the pedal bearings. However, with well-greased ball-bearing joints, any discrepancy in mechanical efficiency should be small. The maximum efficiency of the machine was quite low (37% with no external load, 26% with external load), and an upper limit was set by slipping of the dynamo pulley. Slipping commenced at 60 pedal r.p.m., corresponding to a rate of working of a little over 250 watts (~1550 Kg.m/min); this gives an adequate margin for the testing of normal young men, who are not able to generate power at a rate of more than 140-180 watts over a 5 min period.

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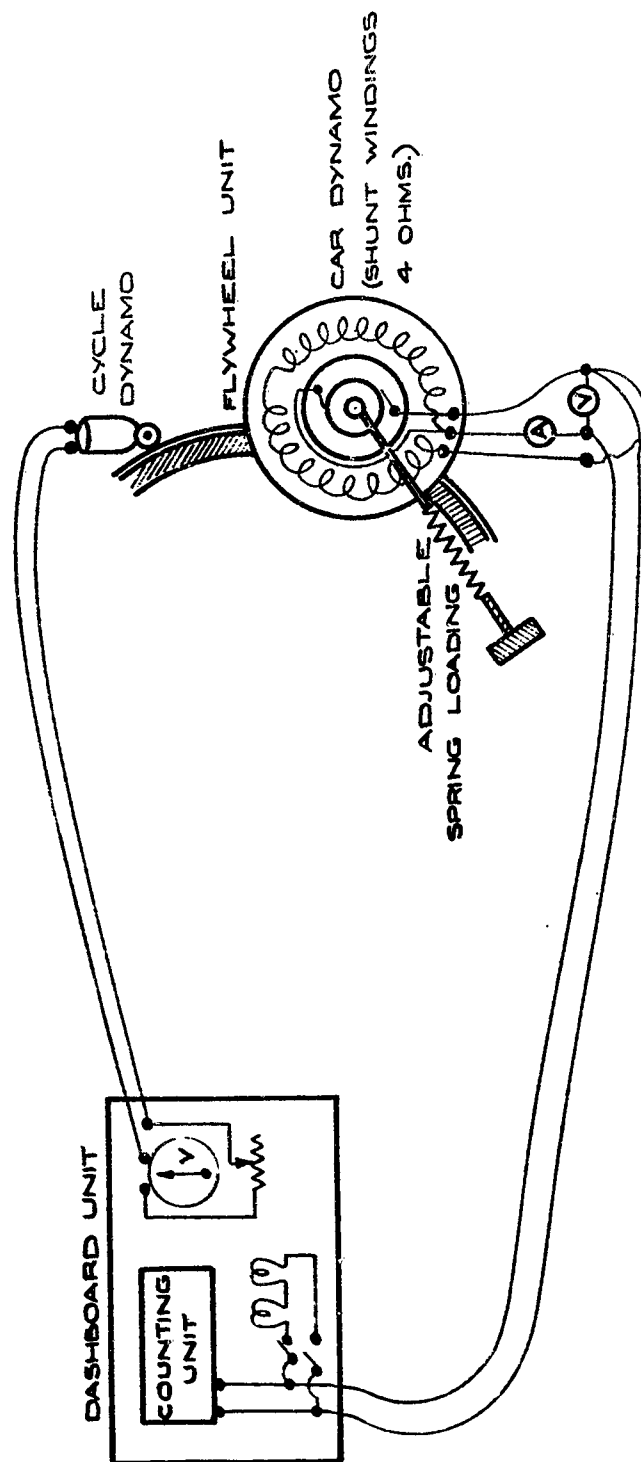
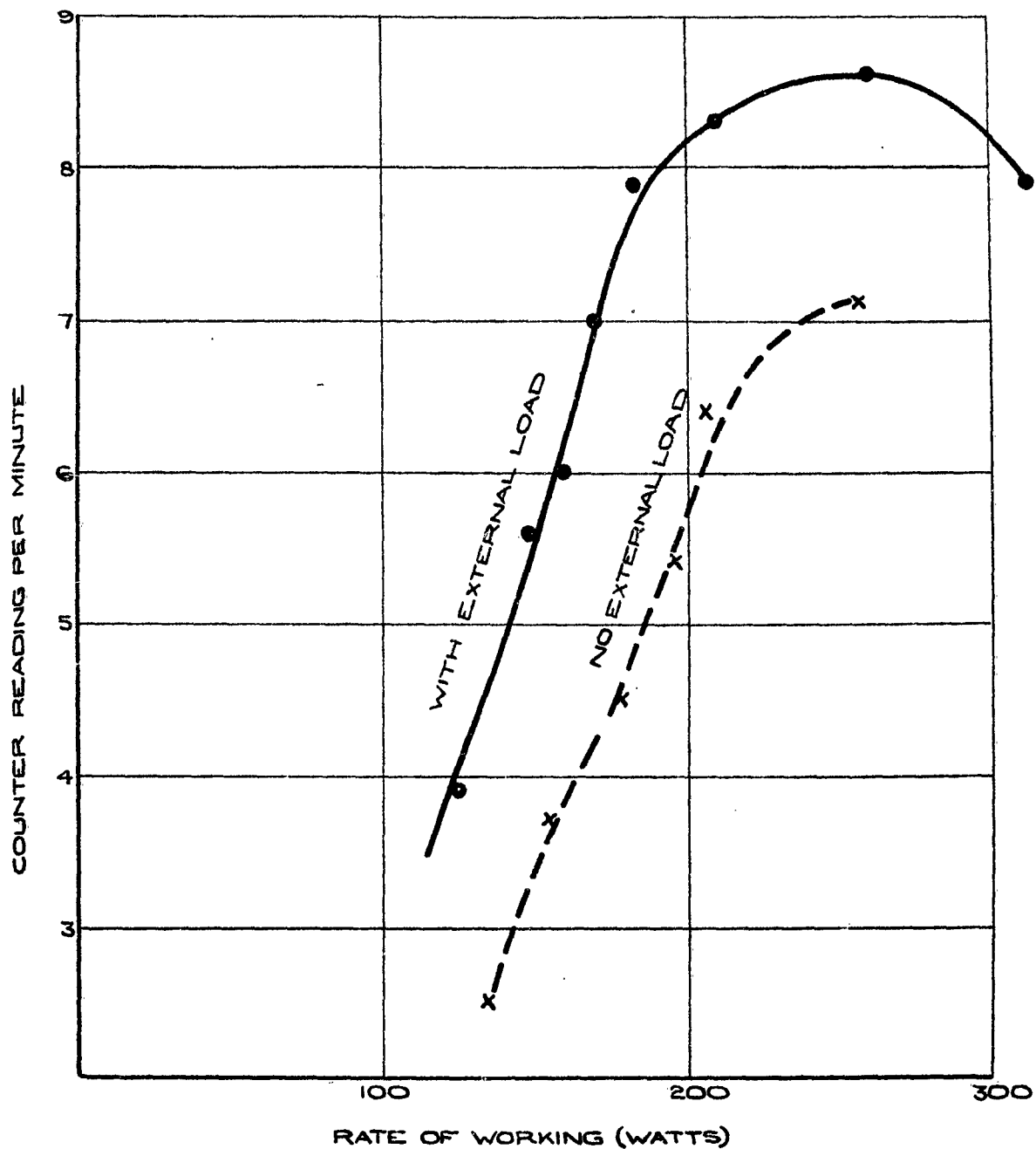


FIG. A.I.

DIAGRAM TO ILLUSTRATE ARRANGEMENT OF
ELECTRICALLY - BRAKED BICYCLE ERGOMETER



CALIBRATION CURVE FOR COUNTER UNIT OF
ELECTRICALLY-BRAKED BICYCLE ERGOMETER.

FIG. A. 2.

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